## Computing a Sustainable Future

Tabatabaei, S.

2018

# Chapter 5

# Comparative analysis of the efficiency of air source heat pumps in different climatic areas of Iran

Seyed Amin Tabatabaei and Jan Treur

**Abstract:** To address the problems caused by fossil energy usage it is important to make a transition to renewable sources of energy, in particular in the residential area. Heating systems such as air source heat pumps that gather heat energy from the ambient air are useful alternatives. However, whether or not such technical solutions are actually used depends on individual decisions. In the current paper the economic aspect for heating is analysed for different regions of Iran and for different pricing strategies for electricity and gas. This is done based on numerical simulations over a year based on temperature data, for domestic heating based on a heat pump in comparison to gas-based heating.

**Keywords:** Air Source Heat Pump; Renewable Energy; Smart Grids; Sustainable Cities; Climate Change; Climatic Areas of Iran

---

This chapter has been published as:
Seyed Amin Tabatabaei, Jan Treur. "Comparative analysis of the efficiency of air source heat pumps in different climatic areas of Iran." In Adolf Sotoca, Ana Catalani, Mahmoud Y. Ghoneem and Mourad S. Amer (eds) Proceedings of the International conference of Improving Sustainability Concept in Developing Countries (ISCDC2015),Procedia Environmental Sciences, Volume 34, 2016, Pages 547-558.

## 5.1 Introduction

Residential energy usage represents about one third of global energy use; around 60 percent of energy in our houses is used for water and space heating. It therefore plays a key role in energy-related environmental problems. To reduce energy consumption, and emission of greenhouse gasses such as $CO_2$ in the residential section, a heating system called Air Source Heat Pump (ASHP) has turned out a good option; such a system can reduce both the emissions and the annual living costs of families.

Residential loads can be classified into two categories: those that can and those that cannot be deferred to later or shifted to earlier times. Lighting is an example of the latter, and examples of the former include washing machines, dishwashers, boilers, fridges and freezers, and also thermal loads. Hence, it is possible to control some of the devices in the home without impacting too much on the lifestyle of the user. In a smart home, it is possible to use an intelligent software agent to control some devices, to shift the loads more to the off peak hours without affecting the lifestyle of users too much. An intelligent agent addressing thermal loads aims to optimize the heating profile (times at which and extent to which the heater is turned on) in order to guarantee that the required temperature is reached at the time one of the inhabitants is present, and the costs of doing so are minimized. Electrical heating and heat pumps can play an important role on future smart cities and smart grids for demand side management. However, this is not exactly the focus of this paper, for more information about this, for example, see [1, 2].

Heat pumps are considered a key energy technology for tomorrow's sustainable cities, as they collect heat from renewable, locally available energy sources such as air, water, ground or waste heat, and produce no direct local emissions. Their ability to couple electrical and thermal energy makes them key components in tomorrow's integrated energy strategies and ideal "partners" in smart energy storage, supply and demand side management, grid balancing and load shifting.

In more developed countries, like the Netherlands, there are high taxes on the prices of fossil fuel based energies for domestic usage, like electricity and natural gas. Actually, by these taxes, people are pushed to use less energy (energy saving) and also to move toward more renewable and green energies. So, this can be an important reason for moving to use heat pumps instead of other heating systems in modern countries. In contrast, in less developed and developing countries, specially those which have large resources of oil or gas, like Iran, there are big subsidies on the prices of natural gas and electricity. To some extent, the subsidies encourage people to use more energy, and not consider alternative sources of energy.

In this paper, by using computational models and available data sets about daily climate factors and changes in some Iranian cities, the yearly performance of an ASHP (used as the main heating system of a house) is estimated. Moreover, a comparative what-if analysis is made for the costs in the case that there are prices with subsidies, real prices and also prices with taxes.

Finally, by comparing the yearly performance of an ASHP in some Iranian cities with different climate characteristics, the effectiveness of using this technology depending on the different climatic areas of Iran has been investigated.

The paper is organized as follows. First, some background information about heat pumps are presented in section 5.2. Then, the simulation is explained in detail. In next Section, simulation results are provided. Section 5.4 is a discussion. Finally, section 5.5 concludes the paper.

## 5.2 Background

In this section some background information is discussed on heating and heat pumps, and about energy pricing in Iran and other countries.

### 5.2.1 Heat pumps

Traditional heating systems are usually based on non-renewable resources such as gas, oil, and coal, which are not sustainable as only limited amounts of them are available. Besides, they have serious negative effects on the environment and climate. Therefore alternative domestic heating systems get much attention nowadays, such as the use of a heat pump (e.g., [3–6]).

#### How does it work?

The second law of thermodynamics states that heat flows naturally from regions of higher temperature (hot source) to regions of lower temperature (cold sink), Figure 5.1. (a). Moreover, heat transfer can be used to do work, and this is happened in heat engines, Figure 5.1.(b). However, It is impossible to extract an amount of heat QH from a hot reservoir and use it all to do work W. Some amount of heat QC must be exhausted to a cold reservoir. On the other hand, heat can be made to flow from a colder region to a hotter region, which is exactly what happens in refrigerators, air conditioners and also heat pumps. But heat only does this when it is forced by W, Figure 5.1.(c).

A heat pump takes thermal energy from the environment (from air, water or soil) and uses this to heat the water of a central heating system in the house. To do this, an amount

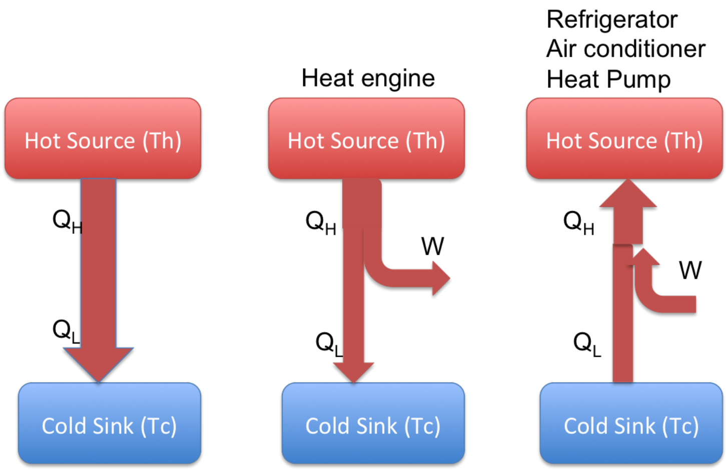


Figure 5.1: (a) Movement of thermal energy from heat source to cold source; (b) Using heat flow to produce work (c) It is possible to convert heat flow, from Cold sink to hot source by doing work

of electrical energy is used to run the heat pump, which is only a fraction of the provided heating energy. An important issue here is that on the coldest days, when heating needs most energy, the air temperature is low, and due to that an air to water heat pump becomes less efficient in use.

### Performance factor of a Heat pump

The performance of a heat pump is described by the seasonal performance factor (SPF), which indicates how much electrical energy (in kWh) is needed, to run the heat pump, as input to get a certain amount of heating energy as output for the heat pump over a certain time period or a season (e.g. [5, 6]):

$$SPF = \frac{Energy\_provided}{Energy\_Used} \tag{5.1}$$

For an ASHP, this performance factor mostly varies between 2 and 5 (e.g., for outdoor temperatures between -5 °C and 15°C); e.g., [7]. Often it is between 3 and 4 (e.g., for ambient temperatures between 2°C and 10°C). It strongly depends on the outdoor temperature, and in particular on the difference between the outdoor temperature and the water temperature of the heating system. To be able to predict the performance of an ASHP, many different formulas are suggested by different researchers. Some of these formulas are reviewed in [8].

#### Different types of heat pumps

Heat pumps acquire up to 60 to 80% of their delivered energy from the heat available in the environment. Only the remaining 20 to 40% is from electricity to drive the device. In the environment it can be taken from the air, the ground, surface water, or from waste heat of industrial processes. Since surface water (like a lake or a river) is not available everywhere, and installing ground source heat pumps need a big investment, many domestic heat pumps harvest their energy from the air (air source, or air to water heat pump). This is the type of heat pump considered in this paper.

#### Studies about heat pumps in Iran

Until now, some Iranian researchers have done studies about heat pumps. Authors of [9] and [10] optimize and design of a ground source heat pump (GSHP) with vertical heat exchangers using different algorithms. While in [11] similar work is reported for a GSHP with horizontal heat exchangers; it is also described how a GSHP for Iranian Fuel Conservation Organization was designed. [12] evaluates the performance of a GSHP installed in a cold city in the northern part of Iran. In a section of [13] the energy saving effects of expanding the usage of heat pump in the capital of Iran is studied.

However, according to the authors' knowledge, this is the first study about using air source heat pumps in Iran. In fact, most research done about the efficiency of the use of heat pumps in Iran, just focuses on geothermal heat pumps; which because of requiring big initial investment, are not the best choice for domestic usage.

### 5.2.2 Central concepts of thermodynamic model of a house

This subsection discusses the theoretical background concerning heating systems and the relation to outdoor temperature $T_{od}$, indoor temperature $T_{in}$ and central concepts characterizing a house such as heat loss rate $\varepsilon$ (depending on insulation level of the house) and heat capacity C of the house (depending on volume of the house), according to [7].

The energy loss of a house per time unit with indoor temperature $T_{id}$ and lower outdoor temperature $T_{od}$ is proportional to the temperature difference between indoor and outdoor temperatures. The proportion factor $\varepsilon$ is the loss rate:

$$\text{energy loss during } \Delta t = \varepsilon(T_{od} - T_{in})\Delta t \tag{5.2}$$

This loss rate depends on the insulation level of the 'skin' of the house: the area in contact with the outside such as the walls, windows, floor and roof.

Another central concept is the heat capacity of a house. The amount of energy needed to increase the indoor temperature is proportional with the difference $\Delta T_{id}$ in indoor temperature. The proportion factor C is the heat capacity:

$$\text{energy needed for heating up} \;=\; C\Delta T_{in} \tag{5.3}$$

The heating capacity C of a house depends on the volume (content) of the house. In a real situation, during a time interval of temperature increase, still some energy loss takes place as well; but in the simulations discussed here it is assumed that heating up is done in just one moment, the lost energy during the heating up is neglected. Moreover, we can use both (5.2) and (5.3) to calculate the changes in $T_{in}$, after loosing energy in a period of time which heating system is not working (cooling down):

$$\Delta T_{in} = \frac{\varepsilon}{C}(T_{in} - T_{od})\Delta t \tag{5.4}$$

Please note that the concepts discussed above can be applied for specific time instants or very short time durations, but they can also be used for longer time periods, such as days, months or seasons. In the latter case, the formulas (5.1), (5.2) and (5.3) can still be applied but some form of summation or integration over time is needed. This has been done in the simulations.

### 5.2.3 Energy prices

Iran is among the countries with the largest fossil fuel reserves (specially oil and natural gas) in the world. As a consequence, the price of energy is much lower in comparison to other countries. Moreover, the Iranian government has subsidized energy products since 1980; and, these subsidies involve a main part of annual budget of the government. However, according to the “subsidy reform plan”, the government is going to remove these subsidies gradually.

#### Current prices in Iran

At the moment (from March 2014 for one year), the bills of electricity and natural gas for domestic buildings are calculated according to a step shaped curve. Each step shows a range of consumption. In the first step (very low consumption), the price is also low; and the price will increase step by step. It means that if a house consumes more, the price will be higher. Table 5.1 shows the prices of electricity for different steps:

For example, if the electricity consumption of a house for one month is 250KWh, then 100kWh is calculated according to the price of the first step, 100kWh according price of the second step, and 50 kWh according to the third one. So, the bill would be

Table 5.1: Price of electricity for domestic usage in Iran

| | Monthly Consumption (KWh) | Price (per KWh) in Rial and Euro [1] |
|---|---|---|
| $1^{st}$ step | 0 to 100 | 409 R = €0.010 |
| $2^{nd}$ step | 100 to 200 | 477 R = €0.012 |
| $3^{rd}$ step | 200 to 300 | 1023 R = €0.026 |
| $4^{th}$ step | 300 to 400 | 1841 R = €0.047 |
| $5^{th}$ step | 400 to 500 | 2114 R =€0.054 |
| $6^{th}$ step | 500 to 600 | 2660 R = €0.068 |
| $7^{th}$ step | More than 600 KWh | 2933 R = €0.075 |

(100×409+100×477+50×1023) 139750 IRR (= €3.583). Please note that in fact some other costs (tax, subscription) are added to this amount, which are not taken into account here.

The pricing mechanism for gas is a bit more complex. There are two different mechanisms for warm and cold months. However, since the focus of this paper is just on cold months, just the pricing mechanism which is used in five cold months is explained.

Most of the Iranian houses use gas-based heating systems during winter time. So, to support the people who live in colder areas, the government has classified the country to four regions. And each region has its own prices. Table 5.2 shows the prices of natural gas for different regions during the winter months. Note that region 1 is the coldest region and region 4 contains the hot cities of Iran.

As an example, if a house in Ahwaz, a hot city in region 4, consumes $310m^3$, then $150m^3$ is calculated according to the price of first step, $100m^3$ according price of second step, and $60m^3$ according to the third one. So, the bill would be (150×414 + 100×690 + 60×966) 189060 Rial = €4.847.

### Real prices in Iran without subsidies

Although currently subsidies are provided with the aim of the government to gradually decrease them in the future. In this paper the costs with and without subsidies are considered and compared. However, it is difficult to have a precise estimation about the real prices of electricity and natural gas without subsidies in Iran. According to the deputy minister of energy, the real price of electricity in Iran is around 950 Rials [2] (September 2015).

However, we could not find any source about the real price of natural gas. So, we have tried to estimate it according to the available information. In the yearly budged program of government for 2010-2011 the real price of gas is calculated as 900 Rials [3] . So, to have an

[2] http://isna.ir/fa/news/94062314625

[3] http://www.magiran.com/npview.asp?ID=2189130&type=

Table 5.2: Price of natural gas (monthly consumption in $m^3$) for domestic usage in Iran

| | Region1 | Region2 | Region3 | Region4 | Price (per m3) in Rial and Euro |
|---|---|---|---|---|---|
| $1^{st}$ step | 0 to 300 | 0 to 250 | 0 to 200 | 0 to 150 | 414 R = €0.0106 |
| $2^{nd}$ step | 300 to 400 | 250 to 350 | 200 to 300 | 150 to 250 | 690 R = €0.0176 |
| $3^{rd}$ step | 400 to 500 | 350 to 450 | 300 to 400 | 250 to 350 | 966 R = €0.0247 |
| $4^{th}$ step | 500 to 600 | 450 to 550 | 400 to 500 | 350 to 450 | 1242 R = €0.0318 |
| $5^{th}$ step | 600 to 700 | 550 to 650 | 500 to 600 | 450 to 550 | 1518 R = €0.0389 |
| $6^{th}$ step | 700 to 800 | 650 to 750 | 600 to 700 | 550 to 650 | 2208 R = €0.0566 |
| $7^{th}$ step | 800 to 900 | 750 to 850 | 700 to 800 | 650 to 750 | 2622 R = €0.0672 |
| $8^{th}$ step | 900 to 1000 | 850 to 950 | 800 to 900 | 750 to 850 | 3036 R = €0.0778 |
| $9^{th}$ step | 1000 to 1100 | 950 to 1050 | 900 to 1000 | 850 to 950 | 3450 R = €0.0884 |
| $10^{th}$ step | 1100 to 1200 | 1050 to 1150 | 1000 to 1100 | 950 to 1050 | 3864 R = €0.0990 |
| $11^{th}$ step | 1200 to 1300 | 1150 to 1250 | 1100 to 1200 | 1050 to 1150 | 4416 R = €0.1132 |
| $12^{th}$ step | > 1300 | > 1250 | > 1200 | > 1150 | 4830 R = €0.1238 |

estimation about the real price of natural gas at 2015, we have to multiply it to the changes of consumer price index [4](219.6 in March 2014, to 82.31 in 2010-2011). So according to our estimation, the real price of natural gas is around (900 $\times$219.6 / 82.3) 2368 Rials or €0.060.

**Prices in a European country (the Netherlands)**

Prices in other countries, for example, the Netherlands in Europe are different. In this country for domestic uage, electricity costs about € 0.22 per kWh. But most of this is tax. Without tax it would be around €0.06 per kWh. For gas the price is about € 0.64 per $m^3$. Half of this is tax, so without tax it would be about € 0.32 per $m^3$.

## 5.3 Simulation

As explained, we have calculated the amount of electricity/natural gas which is required to heat a house in three alternative ways: using a gas-based heating system, electrical heater

[4]http://www.cbi.ir/page/13335.aspx

and also ASHP. Figure 5.2 gives the basic idea of the process. More information about each part is explained in a subsection, mentioned below the ovals.

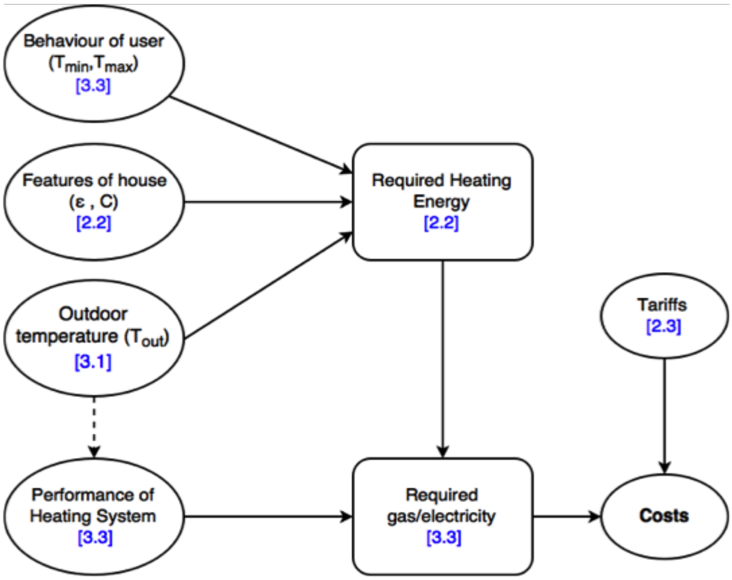


Figure 5.2: The parts of process to calculate the cost for heating up a house during cold months. Description of each part can be found in subsection, mentioned below each element

In this section, first the climatic conditions of the selected cities are explained, then the thermodynamic model of a house is explained and finally, the assumptions for the simulation are described in detail.

### 5.3.1 Datasets

As mentioned, the price of gas in cold months for different Iranian cities and villages is calculated according to its climatic region. So, the price for colder regions is lower then for hot regions. To have a comprehensive view, we have used the hourly temperature datasets of four cities, located in four different regions. These data is downloaded from website of the Iran Meteorological Organization . Table 5.1 explains the climatic situation of these cities.

### 5.3.2 Scenario used

In the simulation, it is assumed that indoor temperatures occur in a range of $[T_{min}, T_{max}]$. When the indoor temperature, $T_{in}$, is higher than $T_{min}$, the heating system will be off; during this time $T_{in}$ will decrease due to cooling down because of cold outdoor temperature. The new

Table 5.3: Brief explanation about the places, that their climatic information is used

| Name | Region Number | Average of temperature in cold months (°C) | Average of daily variance in temperature | Brief Description |
|---|---|---|---|---|
| Tabriz | 1(Cold) | 3.98 | 11.46 | Capital of East Azerbaijan Province, with more than 1.5 million population. Tehran suffers from severe air pollution, especially in cold months. |
| Mashhad | 2 | 6.13 | 13.95 | Capital of Razavi Khorasan Province, with more than 2.5 million population. |
| Tehran | 3 | 8.82 | 7.86 | Tehran is the capital of Iran and Tehran Province. With more than 8 million population. |
| Ahvaz | 4(Hot) | 17.15 | 19.09 | Capital of Khuzestan Province, with more than one million population. Ahwaz has the world's worst air pollution according to a survey by the World Health Organization in 2011. |

indoor temperature can be calculated according to equation (5.4). On the other hand, when $T_{in}$ comes below $T_{min}$, the heating system will generate enough heating energy (calculated according to equation (5.3)) to increase the indoor temperature to $T_{max}$.

As it is depicted in Figure 5.2, the required amount of gas or electricity is dependent to the required heat energy and also the performance of heating system. Unlike gas-based systems and electrical heaters, the performance of an ASHP is not a constant and it varies by changes in the temperature of ambient air.

In the last phase of the simulation, the cost is calculated according to both the required gas or electricity and also tariffs. In this paper, the cost is calculated according to the current tariffs in Iran, the real prices without subsidies, and also the tariffs in an European country (the Netherlands), where government push people to use less fossil fuel based energies by putting high taxes on the price of natural gas and electricity.

### 5.3.3 Details

Since this paper is based on a simulator, we have to make some assumptions about the features of the house, heating devices and also the behavior of the inhabitants of the house. Table 5.4 shows the value of some of the parameters used in the simulator.

Table 5.4: Price of electricity for domestic usage in Iran

| $T_{min}$ | $T_{max}$ | $\varepsilon$ | C | Performance of gas heater | Energy content of 1m3 of natural gas | Performance of electrical heater |
|---|---|---|---|---|---|---|
| 18 | 24 | 10 | 25 | 62% | 10kWh | 100% |

The Iranian national standard organization established an energy consumption label, that all gas-based heaters need to have [5] . According to some reports [6] , non of available gas-based heaters in Iran have label A (performance > 0.85) nor B (0.85 > performance > 0.80). Just 7% have label C (0.80 > performance > 0.75), and 18% have label D (0.75 > performance > 0.70), 38 % have E(0.70 > performance > 0.65), 27 % have F(0.65 > performance > 0.60), and 5% of gas based heaters have G (0.60 > performance > 0.50). The performance of the remaining 5 percent which do not have a standard label is lower than 50% (which means that more than half of the energy is lost). In our simulations, we have considered a gas-based heater with label F. On the other hand, the gross heat of combustion of one cubic meter of natural gas is around 10 kWh.

For an electrical heater, we consider the highest possible performance (100%). And we have used equation (**??**), to have an estimation of performance of ASHP for different outdoor temperatures [8].

$$SPF = 3.547 + 0.147T_{od} + 0.0033T_{od}^2 \tag{5.5}$$

## 5.4 Results

In this section, the results of the simulation experiments are presented.

Figure 5.3 shows the amount of required natural gas or electricity to heating the simulated house. To be more understandable, the first column of this figure shows the monthly average of temperature in each city. The second column shows the monthly required amount of gas, in the case of using a gas-based system. And next columns show the monthly required amount of electricity, in case of using electrical heater and ASHP, respectively. By comparing the bar charts in the third column and charts in fourth column, we can see that the electricity usage of an ASHP is much less than a common electrical heater. However, since the units are different, we cannot easily compare the charts in the second column with others. So, the focus in the next figures is on the monthly costs.

[5] http://www.ifco.ir/building/standard/home/spaceheater.pdf
[6] http://www.payamenaft.com/m-24905.htm

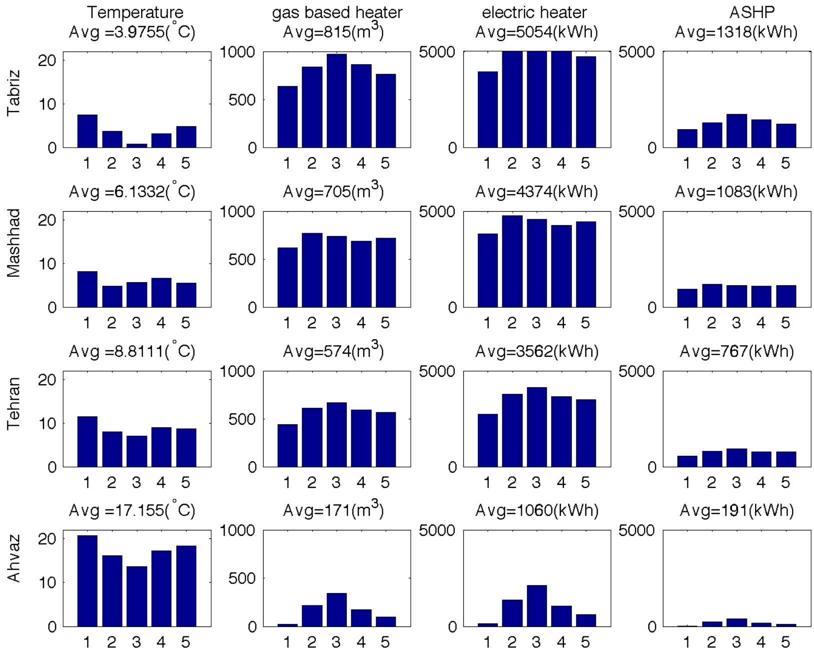


Figure 5.3: Required gas or electricity. Each row is allocated to one city, and the name of cities are written on the left side of rows. The first column shows the average temperature for the five months. The graphs in the second column show how much gas is required if we use a gas-based heating system to heat the simulated house. The third and fourth column shows the required electricity in case of using an electrical heater and ASHP respectively. Please note that the average of bars in each graph is written on top of the graphs.

As is it depicted in Figure 5.4, even though the cost of electricity usage of ASHP is much less than the cost of an electrical heater, still it is higher than costs of a gas-based heater, and it is quite different from the situation in more developed countries. Figure 5.5 shows the cost, in the case of pricing the electricity and gas according to the prices in the Netherlands.

As can be seen in Figure 5.5, according to the prices in the Netherlands the cheapest option is ASHP, while based on the current prices in Iran, using ASHP is much more expensive than gas-based heaters. One main reason for this is that Iran has huge reserves of gas; therefore the price of gas, and energy in general, is less than on international markets. On the other hand, the subsidy policy of Iranian government is another main reason. Next figure shows the cost according to our estimations about the real prices (without subsidies) in Iran.

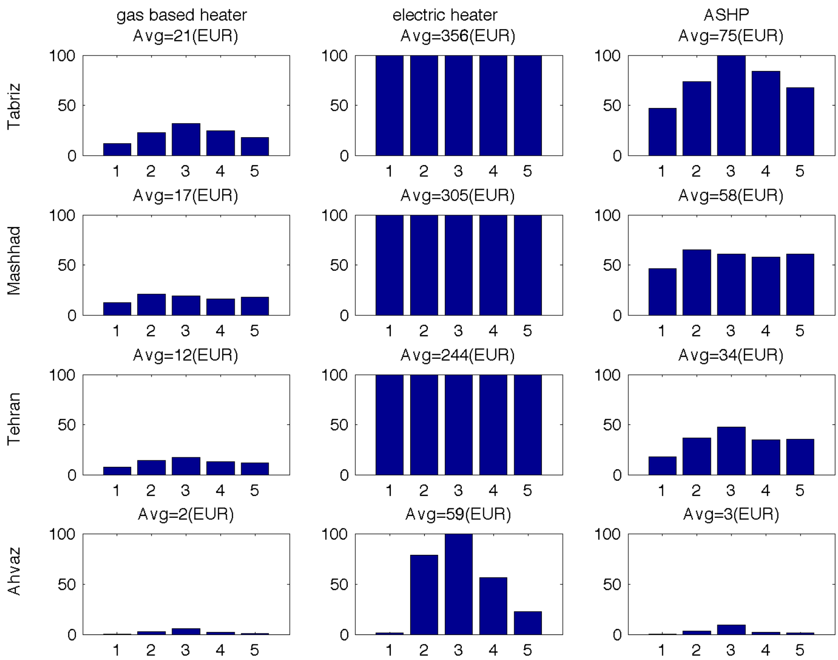


Figure 5.4: Costs of required gas or electricity, according to the current price of natural gas and electricity in Iran. Each row is allocated to one city, and the city names are written on the left side of rows. The graphs in the first column show how much it costs to heat the simulated house using a gas-based heater. The second and third column show the costs of required electricity using an electrical heater and ASHP respectively. Please note that the average of bars in each graph is written on top of the graphs.

According to the result of simulations, depicted in Figure 5.6, not only using ASHP is the cheapest option, but also in cities with hot weather it can reduce the heating costs to less than fifty percent.

## 5.5 Discussion

The analysis made in this paper using simulation experiments for alternative heating systems shows how the annual costs for domestic heating by them strongly depend on the prices of energy sources such as gas and electricity. Given the current pricing in Iran, with subsidies, it will be difficult to persuade home owners to go for the most clean alternatives such as heat pumps and heating by electricity. This has two reasons. In comparison to gas-based

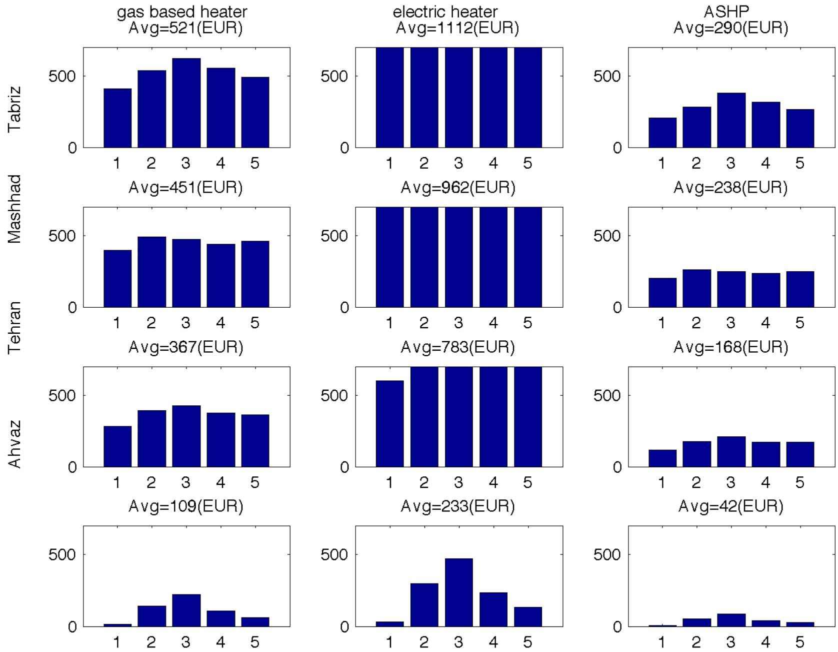


Figure 5.5: Cost of required gas or electricity, according to the current price of natural gas and electricity in the Netherlands. Each row is allocated to one city, and the city names are written on the left side of rows. The graphs in the first column show how much it costs to heat the simulated house using a gas based heater. The second and third column show costs of the required electricity using an electrical heater and ASHP respectively. Please note that the average of the bars in each graph is written on top of the graphs.

heating the initial investment can be too high for the cleaner alternatives, and the monthly costs may be too high for the cleaner alternatives. For electric heaters the second reason plays an important role: they use a lot of electricity. On the other hand, they are quite cheap to buy them. So, to make them an economic alternative, the price of electricity should be extremely low compared to gas, which may not be realistic for Iran. A more realistic alternative, also for Iran, is the use of an air to water heat pump. The electricity used by them for the same heating is about 3 to 4 times lower than heating by electricity, so it is relatively easy to have lower monthly costs than for gas-based heating. However, they are a bit expensive. To buy them will cost an investment up to 2 or 3 times more than for a gas-based heating system. So the gain in monthly costs has to be substantial in comparison to gas-based heating, in order to reach a break-even point, for example, within 10 years. This imposes serious requirements on

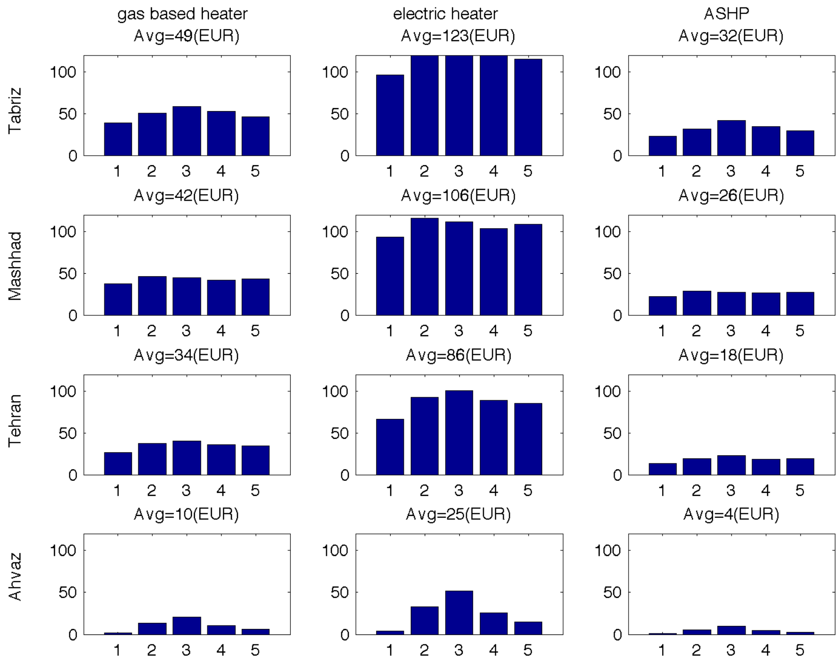


Figure 5.6: Cost of required gas or electricity, according to the real prices in Iran, without subsidies. Each row is allocated to one city, and the city names are written on the left side of rows. The graphs in the first column show how much it costs to heat the simulated house using a gas-based heater. The second and third column show the costs of required electricity using an electrical heater and ASHP respectively. Please note that the average of bars in each graph is written on top of the graphs.

the difference in pricing between electricity and gas. Thus it might still be doubted whether this alternative can become economic for house owners, given the current pricing situation in Iran. But the comparison with prices at the level of a European country (the Netherlands) shows that it is still a feasible option to have levels of prices that make this heat pump as the cleanest alternative for heating economic.

## 5.6 Conclusion and future work

In this paper it is shown how simulation models can be used to find out which type of heating system can be an economic choice in different regions in Iran, thereby taking into account different pricing options. The work reported here can be refined and extended in a number of ways. Some suggestions for future work are:

- Analyzing the available and also the future programs about infrastructure in Iran. For example, maybe there is no need to build new pipelines for giving access to natural gas to new cities, in case of using ASHP for heating. It is more economic both for building and also maintaining new infrastructure.
- Using more detailed models for houses and for the performance of heating systems (e.g., using the information of the outdoor wind and humidity, in addition to temperature)
- A large part of Iran consists of deserts. In these cities, there is a big difference between day temperature and night temperature. So, studying heating systems for cities located in desert can be a possibility for future work.
- Adding heating of hot sanitation water to the simulations
- Performing analysis in a few real case studies of houses in some cities

## Acknowledgements

The authors are grateful to Mr. Mohammad Soltanian from central bank of the Islamic Republic of Iran, who helped us a lot to have better estimations and understanding about the real prices of natural gas and electricity in Iran.

# References


[1] Sarvapali D Ramchurn, Perukrishnen Vytelingum, Alex Rogers, and Nick Jennings. Agent based control for decentralised demand side management in the smart grid. In The 10th International Conference on Autonomous Agents and Multiagent Systems-Volume 1, pages 5–12. International Foundation for Autonomous Agents and Multiagent Systems, 2011.

[2] Seyed Amin Tabatabaei, Dilhan J Thilakarathne, and Jan Treur. An analytical model for mathematical analysis of smart daily energy management for air to water heat pumps. Energy Procedia, 50:589–596, 2014.

[3] KJ Chua, SKm Chou, and WM Yang. Advances in heat pump systems: A review. Applied Energy, 87(12):3611–3624, 2010.

[4] Arif Hepbasli and Yildiz Kalinci. A review of heat pump water heating systems. Renewable and Sustainable Energy Reviews, 13(6):1211–1229, 2009.

[5] Iain Staffell, Dan Brett, Nigel Brandon, and Adam Hawkes. A review of domestic heat pumps. Energy & Environmental Science, 5(11):9291–9306, 2012.

[6] Seyed Amin Tabatabaei, Dilhan J Thilakarathne, and Jan Treur. Agent-based analysis of annual energy usages for domestic heating based on a heat pump. In ICT4S, 2014.

[7] Wim van der Ham, Michel Klein, Seyed Amin Tabatabaei, Dilhan J Thilakarathne, and Jan Treur. Methods for a smart thermostat to estimate the characteristics of a house based on sensor data. Energy Procedia, 95:467–474, 2016.

[8] Seyed Amin Tabatabaei, Jan Treur, and Erik Waumans. Comparative evaluation of different computational models for performance of air source heat pumps based on real world data. Energy Procedia, 95:459–466, 2016.

[9] Hoseyn Sayyaadi, Emad Hadaddi Amlashi, and Majid Amidpour. Multi-objective optimization of a vertical ground source heat pump using evolutionary algorithm. Energy Conversion and Management, 50(8):2035–2046, 2009.

[10] Sepehr Sanaye and Behzad Niroomand. Thermal-economic modeling and optimization of vertical ground-coupled heat pump. Energy Conversion and Management, 50(4):1136–1147, 2009.

[11] Sepehr Sanaye and Behzad Niroomand. Horizontal ground coupled heat pump: Thermal-economic modeling and optimization. Energy conversion and management, 51(12):2600–2612, 2010.

[12] Mortaza Yari and Nader Javani. Performance assessment of a horizontal-coil geothermal heat pump. International Journal of Energy Research, 31(3):288–299, 2007.

[13] Majid Abbaspour, Abdolreza Karbassi, Morteza Khalaji Asadi, Naser Moharamnejad, Samira Khadivi, and Mohammad Ali Moradi. Energy demand model of the household sector and its application in developing metropolitan cities (case study: Tehran). Polish Journal of Environmental Studies, 22(2), 2013.